ANDEEN-HAGERLING, INC.

manufacturers of the world's most accurate capacitance bridges and standards

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Selected Publications discussing applications of Andeen-Hagerling Capacitance Bridges and AH1100/AH11A Fused-Silica Standards and Frame along with some side-notes

As of May 2009

4. ELECTRICAL / CAPACITANCE METROLOGY

National Measurement Institutes/Laboratories

The **AH1100/11A** capacitance **standards** are the world's most stable standards (0.3 + 1/C ppm per year stability, where C is the value in pF). Their accuracy is traceable to about 2 ppm. High-level calibration laboratories throughout the world are the major users of these standards for primary calibrations or as transfer standards from higher-level standards (quantum hall or calculable capacitor standards).

These standards are also subject of the article, **"Measurement of Voltage Coefficients of Fused-silica Standard Capacitors"**, Atushi Domae and Yasuhiro Nakamura, (NMIJ / AIST), **IEE Japan**, March 26-29, 2002, pp. 276-277, where the **AH11A** fused-silica capacitors are carefully measured.

"Environmental Management in a Standards Room for Measuring Air Capacitors", Makoto Kasuga, Akiu Yamazaki, Katsumi Yokoi; **NCSLI 2003**, Tampa, FL, August 20, 2003.

"Determination of the von Klitzing constant R_K in terms of the BNM calculable capacitor - fifteen years of investigations", G. Trapon, O. Thevenot, J. C. Lacueille, W. Poirier; **Metrologia**, Volume 40, Issue 4, August 2003, pp. 159-171.

"Electronics and Electrical Engineering Laboratory, Electricity Division - Programs, Activities, and Accomplishments", **NIST**, January 2003.

"International Comparisons of Capacitance, Magnetic Flux and AC Voltage Ratio", Stephen Bryant, NPL (UK); **DC and LF News**, Issue 15, Summer 2003.

"Evaluation of the Uncertainty in the Realization of the PLTS-2000 at NMi", A. Peruzzi, M. J. de Groot; **Bureau International des Poids et Mesures (BIPM),** Consultative Committee for Thermometry.

"Evaluation of Uncertainty in the Realization of the Provisional Low Temperature Scale from 10 mK to 1 K at Nmi", A. Peruzzi, M. J. de Groot, in **Proceedings of the International Conference on the Uncertainty of Measurement UNCERT 2003,** St. Catherine's College, Oxford, UK, April 9-10, 2003; this paper was also submitted to the CCT in April 2003.

"Uncertainty Budget for the Realization of the Provisional Low Temperature Scale of the PLTS-2000 at PTB", J. Engert, B. Fellmuth, A. Hoffmann; **Bureau International des Poids et Mesures (BIPM)**, Consultative Committee for Thermometry.

"Linking the Results of 10 pF Capacitance Key Comparisons CCEM-K4 and Euromet 345", F. Delahaye, T. J. Witt; **Conference on Precision Electromagnetic Measurements**, Ottawa, Canada, June 16-21, 2002, Conference Digest.

"A New, Larger Cryogenic Capacitor, and a Direct Comparison to the Calculable Capacitor", Mahmoud A. El Sabbagh, Yichen Wang, Neil M. Zimmerman; **Conference on Precision Electromagnetic Measurements**, Ottawa, Canada, June 16-21, 2002, Conference Digest.

A recent article, **"A Day in the Life of NIST"**, in **Test & Measurement World**, by Martin Rowe, Senior Technical Editor, December 2000, pp. 57-64, noted that National Institute of Standards and Technology (NIST) uses the **AH2500A** bridge [this is an **Option E** bridge] to calibrate nitrogen-dielectric capacitors with best uncertainties of 4 ppm [these are capacitors like the GenRad 1404].

The **AH2500A** was the "precision capacitance bridge" part of the equipment used to calibrate four-terminal pair (4TP) admittance standards. These admittance standards are used to calibrate 4TP LCR meters and 4TP impedance analyzers to frequencies up to around 10 MHz. (**"A New Universal Calibration Method for Four-Terminal-Pair Admittance Standards"**, Kiyoshi Suzuki, Yokagawa-Hewlett Packard, Ltd., Tokyo, Japan) in **IEEE Transactions On Instrumentation and Measurement**, Volume 40, Issue 2, April 1991, pp. 420-422.

In **"Calibration of a Ratio Transformer"**, Toshiaki Aoki, Katsumi Yokoi, (Agilent Measurement Standards Center, Tokyo, Japan), **1995 National Conference of Standards Laboratories (NCSL) Workshop & Symposium Proceedings**, pp. 701-707, the authors describe a calibration technique for decade ratio transformers using the **AH2500A** capacitance bridge and other instruments.

The **AH1100/11A's** were used as part of an **"Intercomparison of 10 pF and 100 pF Capacitance Standards"**. The National Physical Laboratory of the UK as NPL Report CEM 7 published the results as **EUROMET Project Reference Number 345**. The testing took place from 1995 through 1998 between more than 10 national laboratories around the world.

And as we begin to look more carefully at the frequency dependence of precision standard capacitors, Yasuhiro Nakamura, Masakazu Nakanishi, and Tadashi Endo, in **"Measurement of Frequency Dependence of Standard Capacitors Based on the QHR in the Range Between 1 kHz and 1.592 kHz"**, **IEEE Transactions on Instrumentation and Measurement**, Volume 50, Issue 2, April 2001, pp. 290-293, measured a rather small frequency dependence with the 10 pF **AH11A** fused-silica standards. When compared with other fused-silica standards, these were quite favorable and demonstrated to the authors that the frequency dependencies of these standards could be measured relative to QHR.

"Bilateral Comparison of 10 pF and 100 pF Capacitance Standards between the NPL and the BIPM, April/May 2002", F. Delahaye, S. A. Awan; **Bureau International des Poids et Measures (BIPM),** January 2003.

"Bilateral Comparison of 100 pF Capacitance Standards between the NML, Ireland and the BIPM, January/April 2004", O. Power, F. Delahaye; **Bureau International des Poids et Measures (BIPM)**, July 2004.

"Measurements Of Frequency Dependence Of Fused-Silica Capacitors", Yicheng Wang, National Institute of Standards and Technology, Gaithersburg, MD, USA; paper presented at **National Conference of Standards Laboratories International (NCSLI) Annual Symposium**, Aug. 2003, Tampa FL. This paper reports on work done by National Institute of Standards and Technology (NIST) on the frequency response of two, transportable **AH11A** fused-silica standards as measured by a 1 pF cross-capacitor and a 10 pF nitrogen dielectric capacitor. The **AH2700A** multi-frequency bridge is then used to measure these capacitors at frequencies from 50 Hz to 20 kHz. "The relative standard uncertainties determined at 400 Hz and 100 Hz are smaller than the frequency related uncertainties previously assigned by a factor of five and will lead to improvements in the capacitance calibration services provided by National Institute of Standards and Technology (NIST).

"Calibration Method For Four-Terminal-Pair Capacitance Standards: Progress Report", T. Aoki, K. Susuki, K. Yokoi; **Conference on Precision Electromagnetic Measurements**, Washington, DC, July 6-10, 1998, Conference Digest.

"Ultra Low Temperature Behaviour of a Cryogenic Vacuum Gap Capacitor", Paul Teunissen, Erik Dierikx, Gert Rietveld; **Conference on Precision Electromagnetic Measurements**, Sydney, Australia, May 14-19, 2000, Conference Digest.

"Maintenance and Development of the Capacitance Unit at CENAM", J. Angel Moreno; **Conference on Precision Electromagnetic Measurements**, Sydney, Australia, May 14-19, 2000, Conference Digest.

"Pressure Coefficients of Air Dielectric Capacitors", Patricia Thomas and Thomas Wunch of Sandia National Laboratory, **National Conference of Standards Laboratories International (NCSLI) 2003**, Tampa, Florida, August 17-23, 2003.

"Larger Value and SI Measurement of the Improved Cryogenic Capacitor for the Electron-Counting Capacitance Standard", Neil M. Zimmerman, Mahmoud A. El Sabbagh, Member, IEEE, and Yicheng Wang, Senior Member, IEEE; **IEEE Transactions on Instrumentation and Measurement**, Volume 52, Issue 2, April 2003, pp. 608-611.

"Frequency Dependence of Capacitance Standards", Yicheng Wang; **Review of Scientific Instruments**, Volume 74, Issue 9, September 2003, pp. 4212-4216.

"An Easy-To-Use Combination Four-Terminal-Pair/Two-Terminal-Pair AC Transformer Bridge", A. Jeffery, J. Q. Shields, L. H. Lee; **Journal of Research of the National Institute of Standards and Technology**, Volume 103, Number 2, March-April 1998, pp. 163-166.

"Frequency Dependence of Fused-Silica Capacitors", Yicheng Wang, Andrew Koffman, Scott Shields, Lai Lee of Electricity Division, **NIST.**

"Supplementary Investigations to PTB's Evaluation of G", Winfried Michaelis, Jurgen Melcher, Holger Haars; **Metrologia**, Volume 41, Issue 6, December 2004, pp. L29-L32.

"Calibration of RLC Meters in Ranges for Measuring of High Inductance Values", Asst. Prof. Dr. J. Horsky, Dr. J. Horska; **The International Congress Of Metrology**, Lyon, France, June 20-23, 2005.

"Optimizing the Use of Commercial Capacitance Bridges in Fused-Silica Standard Capacitor Calibrations at NIST", Yicheng Wang, Scott Shields; **2005 NCSL International Workshop and Symposium**, Washington, D.C., August 7-11, 2005.

"10-nF Capacitance Transfer Standard", Luca Callegaro, Vincenzo D'Elia, Danilo Serazio; **IEEE Transactions on Instrumentation and Measurement**, Volume 54, Issue 5, October 2005, pp. 1869-1872.

"Precision Computer-Controlled Decade Capacitor", Heinz Eckardt, Heinz-Günther Behnke, Werner Bemme, Yuri P. Semyonov, Oleg A. Shvedov; **IEEE Transactions on Instrumentation and Measurement**, Volume 48, Issue 2, April 1999, pp. 360-364.

"New Capability for Generating and Measuring Small DC Currents at NPL", N. E. Fletcher, S. P. Giblin, J. M. Williams, K. Lines; **CPEM 2006 Digest**, Conference on Precision Electromagnetic Measurements, Torino, Italy, July 9-14, 2006, pp. 152-153.

"International Comparison of 10pF and 100pF Capacitance Standards: Degrees of Equivalence Determination in the Coomet Project 345/UA/05", S. Akhmadov, O. Akhmadov, O. Velychko; **CPEM 2006 Digest**, Conference on Precision Electromagnetic Measurements, Torino, Italy, July 9-14, 2006, p. 185.

"Bilateral Comparison MIKES – SP of Calibration of 1nF, 10nF, 100nF, and 1μF Capacitors", A. Satrapinski, G. Eklund; **CPEM 2006 Digest**, Conference on Precision Electromagnetic Measurements, Torino, Italy, July 9-14, 2006, pp. 202-203.

"A Two Terminal-Pair Coaxial Capacitance Bridge Constructed at INMETRO", G. A. Kyriazis, R. T. B. Vasconcellos, L. M. Ogino, J. Melcher, J. A. Moreno; **CPEM 2006 Digest**, Conference on Precision Electromagnetic Measurements, Torino, Italy, July 9-14, 2006, pp. 522-523.

"A Calibration Procedure for a Programmable Capacitance Standard", Svetlana Avramov-Zamurovic, Bryan C. Waltrip, Andrew D. Koffman; **CPEM 2006 Digest**, Conference on Precision Electromagnetic Measurements, Torino, Italy, July 9-14, 2006, pp. 648-649.

"Dissipation Factors of Fused-Silica Capacitors in the Audio Frequency Range", Yicheng Wang, Andrew Koffman, Gerald FitzPatrick; **CPEM 2006 Digest**, Conference on Precision Electromagnetic Measurements, Torino, Italy, July 9-14, 2006, pp. 654-655.

"Bridges for the Realization of the Units and Build-up of the Scale for Electrical Resistance, Capacitance and Inductance", M. Surdu, A. Lameko, I. Karpov, A. Koffman, J. Kinard, M. Klonz, J. Melcher, A. Tarlowsky; **CPEM 2006 Digest**, Conference on Precision Electromagnetic Measurements, Torino, Italy, July 9-14, 2006, pp. 520-521.

"Traceability Chains of Czech Metrology Institute with Regard to Impedance Standards", Jiri Horsky; **MAPAN – Journal of Metrology Society of India**, Volume 18, Number 3, 2003, pp. 199-205.

"Evaluation of the Frequency Dependence of the Resistance and Capacitance Standards in the BIPM Quadrature Bridge", Francois Delahaye, Roland Goebel; **IEEE Transactions on Instrumentation and Measurement**, Volume 54, Number 2, April 2005, pp. 533-537.

"Improved Capacitance Measurements With Respect to a 1-pF Cross-Capacitor From 200 to 2000 Hz", Yicheng Wang, Scott H. Shields; **IEEE Transactions on Instrumentation and Measurement**, Volume 54, Number 2, April 2005, pp. 542-545.

"A Digitally Programmable Capacitance Standard", Yicheng Wang, Lai Lee; **Review of Scientific Instruments**, Volume 75, Issue 4, April 2004, pp. 1158-1160.

"Measurements of frequency dependence of fused-silica capacitors", Yicheng Wang; **2003 NCSL International Workshop and Symposium**, Tampa, Florida, August 11-17, 2003.

"A Tunable Vacuum-Gap Cryogenic Coaxial Capacitor", Frédéric Overney, Blaise Jeanneret, Miha Furlan; **IEEE Transactions on Instrumentation and Measurement**, Volume 49, Number 6, December 2000, pp. 1326-1330.

"Developing a Calibration Service for Dissipation Factor for Standard Capacitors at NIST", Andrew Koffman, **2007 NCSL International Workshop and Symposium**, St. Paul, Minnesota, July 30, 2007 to August 1, 2007.

"Direct Determination of Capacitance Standards Using a Quadrature Bridge and a Pair of Quantized Hall Resistors", A. D. Inglis, B. M. Wood, M. Côté, R. B. Young, M. D. Early; **IEEE Transactions on Instrumentation and Measurement**, Volume 52, Number 2, April 2003, pp. 559-562.

"Protocol for capacitance comparison", National Measurement Institute, **http://www.measurement.gov.au**

"Uncertainty budget for the NIST electron counting capacitance standard, ECCS-1", Mark W. Keller, Neil M. Zimmerman, Ali L. Eichenberger; **Metrologia**, Volume 44, Number 6, December 2007, p. 505.

"Evaluation of a Capacitance Scaling System", S. Avramov-Zamurovic, A. D. Koffman, B. C. Waltrip, Yicheng Wang; **IEEE Transactions on Instrumentation and Measurement**, Volume 56, Issue 6, December 2007 pp. 2160-2163.

NOTE TO OUR READERS: If you have published an article that is not mentioned in this document referencing the use of one of our instruments, please let us know about it. Capacitance is a powerful tool for many situations. However, it takes continuous proof by example to show its value among so many other competing technologies.